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Budget allocation for water mains rehabilitation projects using Simos' procedure

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Factors grade scales

Abstract Water mains rehabilitation projects' budget allocation is considered the most important challenge that faces the engineers and the decision maker in governments and municipalities, especially when it is limited. This paper presents a methodology for water mains rehabilitation projects' budget allocation. The proposed methodology consists of two models: (1) the grade classification model; and (2) the project ranking model. The grade classification model uses significant sustainability development criteria such as: economic; social; and environmental criteria. The main function of the grade classification model is to classify the projects into five grade level (lowest, low, medium, high, and very high), whereas, the main function of the project ranking model is to rank the projects at the same level in descending order according to their weighted scoring value. A factor's numerical grade scales have been established to adjust the factor's scoring in the project ranking model. Simos' procedure is integrated with the scoring factors model to develop the grade classification model. A numerical example is provided to demonstrate the proposed methodology.

Introduction

The budget is a fiscal plan for a certain period. Allocating the limited budget for water mains rehabilitation projects needs effective methods to evaluate and prioritize the projects. The main task of this research is to provide a method for effective budget allocation, putting the budget to the best use and maximizing the function of the limited budget. In the literature there are various criteria to evaluate and select using multiple criteria decision making methods (MCDMM). Vainer et al. [1] indicated that the maintenance and replacement (M&R) alternatives should be selected according to data belong to current state of the infrastructure assets, the relative risk of failure of these assets, the initial costs, and life cycle costs of proposed interventions, and through techniques such as, single criterion, or multi-criteria techniques. The multi-attribute theory method is used to evaluate and select alternatives. Mohamed and Zayed [2] used the multi-attribute utility theory to develop a prioritization fund allocation model for water mains rehabilitation projects. They used factors belong to pipe criteria, operational criteria, and community criteria. Multi-criteria modeling techniques are used to assist in selecting and

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Abbreviations

MCDMM	multiple criteria decision making method
M&R	maintenance and replacement
PI	priority index
AHP	analytic hierarchy process
ANN	artificial neural network
O&M	operational and maintenance
IRR	internal return ratio

evaluating the alternatives. Huang et al. [3] applied multi-criteria modeling technique to develop a budget allocation model for the public infrastructure projects. The proposed model integrates three sub-models: the fuzzy multi-criteria grade classification model; the fuzzy multi-criteria project ranking model; and the budget allocation model. The proposed model allows for ready reactions to changes of budget policies. One of the most used techniques is the priority index modeling technique. This technique uses weighted scoring factors to calculate the priority index (PI) for evaluating the alternatives. Zayed and Mohamed [4] developed a priority index (PI) model to allocate fund to the water systems projects. The proposed model assists in developing a renewal plan for water networks. The InfraGuide [5] provided two approaches for developing water mains renewal plan, the topdown and bottomup approaches. This plan contributes in allocating budget to the water mains rehabilitation projects. The integration of the analytic hierarchy process and artificial neural network is used to evaluate municipal water mains' performance. Al-Barqawi and Zayed [6] developed a model to assess the condition and predict the performance of water mains using the AHP/ANN model. The InfraGuide [7] concept of asset management helps in solving the challenge of funding the water mains rehabilitation projects. The concept of asset management uses the bottom-up approach for short term planning and the top-down approach for long term planning. The top-down approach is used for strategic long term planning of a group of components of water distribution projects, whereas, the bottom-up approach is used for short-term planning of each component of water distribution projects. The sustainability development criteria are used in the evaluation and projects selection. The application of key assessment indicators helps decision makers in selecting the appropriate projects. Shen et al. [8] proposed key assessment indicators for assessing the sustainability performance of an infrastructure project to help the decision makers to evaluate and assess the sustainability performance of infrastructure projects. Marzouk and Abdelaty [9] developed a rating system using Simos' ranking method in order to determine the weights of different components contributing in the whole level of service of the subway station's network and maintenance priority indices. The developed framework is capable to monitor the indoor temperature and the particulate matter (PM) concentration levels in subways stations. Hellstrom et al. [10] described a framework for systems analysis of sustainable urban water management and gave a set of sustainability criteria. The framework is part of large national research program in Sweden entitled "Sustainable Urban Water Management." A set of sustainability criteria that are related to health and hygiene, social and cultural aspects, environmental aspects, economy and technical considerations were considered.

Arriartanam et al. [11] proposed a sustainability index for evaluating infrastructure technology based on environmental impacts. The sustainability index enables decision makers to quantify public works utility projects with guidance for evaluating proposed technologies based on environmental impact, costs, and social impact criteria. Teng et al. [12] provided an empirical study of the budget allocation in transportation projects. The study provided a model to allocate budgets of the transportation projects. The model is limited to construction projects that have completed feasibility evaluations and the model cannot be used for different allocations for projects with different resources demands. Marzouk et al. [13] carried out a study for selecting the right equipment using the superiority and inferiority ranking methods. Several interviews and two questionnaires have been taken place to gather the important factors that contribute in the equipment selection processes. The factors' weights were calculated using the AHP method. The study provided a model utilizes the AHP scoring method and SIR method. Roberts and Broadbent [14] used the weighted scoring factors model for prioritizing the water mains rehabilitation projects. Prioritize based on risk and use unit cost data and budget information to create a pipe rehabilitation plan. Evaluation and selection of industrial projects for investment need effective method of evaluations. Marzouk et al. [15] developed a feasibility study for selecting the suitable industrial projects for investment using Simos' procedure. The Simos' procedure was integrated with the weighted sum model to aim in the selection of the preferred industrial project. Figueira and Bernard [16] used the revised Simos' procedure to determine the weights in the ELECTRE type methods. Simos' procedure was used for two main reasons: (1) the way that Simos recommends the information is based on unrealistic assumptions; (2) it leads to processes criteria having the same importance. Prioritizing water mains for rehabilitation need an assessment technique to rank the water mains according to their severity condition. Marzouk et al. [17] developed a methodology for prioritizing the water mains rehabilitation in Egypt. The methodology aims in ranking the water mains according to their severity condition. The methodology helps the decision makers to make a decision for the rehabilitation of the water mains that have a higher priority index (PI). This paper presents a budget allocation methodology for water mains rehabilitation projects. The methodology helps the decision makers to prioritize the projects to allocate the budget, especially in case of the limited available budget.

Research methodology

Interviews were conducted after reviewing past research in the field of water mains including deterioration models, weighted scoring factors decision making modeling, and water mains rehabilitation project's budget allocation. Simos' procedure was used to calculate the factors' relative weight. The purpose of the interviews with experts in the field of water distribution systems was to gather a list of factors that contribute in the budget allocation of water mains, to collect data for calculating the factors' relative weight using Simos' procedure, and creating factors' grade scales. Subsequently, water mains rehabilitation projects' budget allocation model is developed. The development includes two models: (1) The grade classification model; and (2) The project ranking model. Fig. 1 illustrates the research methodology.

Grade classification model development

A preliminary list of thirteen factors has been gathered from the literature and reviewed by water distribution systems specialists. The factors are categorized into three main clusters: (1) Economic factors; (2) Social factors; and (3) Environmental factors as shown in Table 1. Interviews with four experts have been conducted to discuss and verify the preliminary list of factors [4]. The gathered factors include: (1) project capital cost; (2) project operational and maintenance cost (O&M); (3) payback period; (4) internal return ratio; (5) effects on other nearest properties; (6) effect on traffic; (7) effect on public health; (8) effect on other nearest utilities; (9) effect on public safety; (10) effect on air quality; (11) effect on water quality; (12) noise effect; and (13) energy saving as shown in Table 1.

The main purpose of this model is to classify the water mains rehabilitation projects into five grades: the very low grade projects, the low grade projects, the medium grade projects, the high grade projects, and the very high grade projects. The projects at very high grade will take the budget first; those at lower grade can be implemented, depending on how much of the budget is left.

Simos' procedure was used to calculate the factors' relative weights through two steps: (1) collecting data belong to the relative weight of the factors through experts' interview as shown in Table 2, and (2) calculating the relative normalized weights and global weights for the factors as shown in Tables 3 and 4. Interviews with six experts have been conducted. The experts were asked to rank the factors of each cluster in ascending order from the lowest important factor to the most important one as shown in Table 2. Also, they were asked to rank the main clusters in ascending order from the lowest important cluster to the most important one as shown in Table 2. The respondents Q1, Q2, Q3, Q4, Q5, and Q6 are

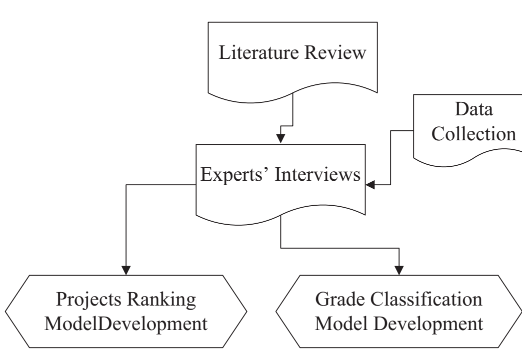

Figure 1 Budget allocation model development methodology.

Table 1 Grade classification factors.

Main clusters	Factor	Preferences
Economic factors	1. Project capital cost	The project with lower capital cost is preferred
	2. Project operational and maintenance costs (O&M)	The project with lower operational and maintenance cost is preferred
	3. Payback period	The faster payback period is preferred
	4. internal return ratio (IRR)	The higher ratio is preferred
Social factors	5. Effect on other nearest properties to the host pipes	The lower effect on other properties is preferred
	6. Effect on traffic	The lower disruption effect on traffic is preferred
	7. Effect on public health	The lower negative effect on public health is preferred
	8. Effect on other nearest utilities to the host pipes	The lower damage effect on other utilities is preferred
Environmental factors	9. Effect on public safety	The lower negative effect on public safety is preferred
	10. Effect on air quality	The lower negative effect on air quality is preferred
	11. Effect on water quality	The lower negative effect on water quality is preferred
	12. Noise effect	The lower noise effect is preferred
	13. Energy saving	The higher energy saving is preferred

the experts' feedback for calculating the factors' relative weights using Simos' procedure. The F1 factor has the average value (Q1 + Q2 + Q3 + Q4 + Q5 + Q6)/6 equals 3.5, F2 has average value equals 3.2, F3 has average value equals 1.7, and F4 has average value equals 1.7. The Simos' rank for these group of factors will be one for factor F4, and F3, two for F2, and three for F1. F5 has average relative weight value equals 1.5; F6, F7, and F8 have average relative weight value equals 2.8. F5 has Simos rank value 1, and F6, F7, and F8 have Simos rank value 2. F9 has average relative weight equals 2.7, F10 has average value 2.2, F11 has average value 3.5, F12 has average value 2.8, and F13 has average value 3.8. F10 takes the 1st rank, F9 takes the 2nd rank, F12 takes the 3rd rank, F11 takes the 4th rank, and F13 takes the 5th rank. The economic cluster has average relative weight equals 2.3 and has the 3rd rank, social cluster has average relative weight equals 1.5 and takes the 1st rank, and Environmental cluster has average relative weight equals 2.2 and takes the 2nd rank.

For each cluster, the factors are grouped in sub-groups that have the same Simos' rank as shown in the first column of Table 3. The second column has the number of factors in each sub-group. The position column in Table 3 contains the position of the factors in each sub-group. The normalized relative weight of the factor was calculated by dividing the non-normalized weight of the factor by the total sum of the position column for each cluster's factors, and the same was followed

Table 2 Experts' feedback.

Main clusters	Factor	Q1	Q2	Q3	Q4	Q5	Q6	Average	Simos' Rank
Economic	(F1) Project Capital cost	3	4	3	4	4	3	3.5	3
	(F2) Project (O&M) costs	4	3	2	3	3	4	3.2	2
	(F3) Payback period	1	2	1	2	2	2	1.7	1
	(F4) Internal return ratio (IRR)	2	1	4	1	1	1	1.7	1
Social	(F5) Effect on other nearest properties to the host pipes	1	1	2	1	1	3	1.5	1
	(F6) Effect on traffic	2	3	4	4	3	1	2.8	2
	(F7) Effect on public health	4	4	1	2	2	4	2.8	2
	(F8) Effect on other (nearest) utilities to the host pipes	3	2	3	3	4	2	2.8	2
Environmental	(F9) Effect on public safety	5	3	3	3	1	1	2.7	2
	(F10) Effect on air quality	1	2	2	4	2	2	2.2	1
	(F11) Effect on water quality	3	5	1	5	3	4	3.5	4
	(F12) Noise effect	2	1	5	2	4	3	2.8	3
	(F13) Energy saving	4	4	4	1	5	5	3.8	5
Main clusters	1. Economic	1	3	2	3	3	2	2.3	3
	2. Social	3	1	1	2	1	1	1.5	1
	3. Environmental	2	2	3	1	2	3	2.2	2

Table 3 Factors' relative weights calculations.

Factor/sub-group of factors/main clusters	No. of factors	Position (Simos' Rank)	Non-normalized weight (position)	Normalized weight	Total normalized weight
Project capital cost	1	3	3	(3/7) * 100 = 43	43
Project operational and maintenance costs (O&M)	1	2	2	(2/7) * 100 = 29	29
{Payback period, internal return ratio (IRR)}	2	1 1	1	(1/7) * 100 = 14	28
Sum	4	7			100
Effect on other nearest properties	1	1	1	(1/7) * 100 = 14	14
{Effect on traffic, effect on public health, effect on other nearest utilities}	3	2 2 2	2	(2/7) * 100 = 29	87
Sum	4	7			101
Effect on public safety	1	2	2	(2/15) * 100 = 13	13
Effect on air quality	1	1	1	(1/15) * 100 = 7	7
Effect on water quality	1	4	4	(4/15) * 100 = 27	27
Noise effect	1	3	3	(3/15) * 100 = 20	20
Energy saving	1	5	5	(5/15) * 100 = 33	33
Sum	5	15			100
Economic main clusters	1	3	3	(3/6) * 100 = 50	50
Social main clusters	1	1	1	(1/6) * 100 = 17	17
Environmental main clusters	1	2	2	(2/6) * 100 = 33	33
Sum	3	6			100

for the main clusters as shown in Table 3. The calculated normalized relative weights of the thirteen factors from F1 to F13 were, 43%, 29%, 14%, 14%, 14%, 29%, 29%, 29%, 13%, 7%, 27%, 20%, and 33% respectively. The normalized relative weight of the economic factors equals 50%, the normalized relative weight of the environmental factors equals 33%, and the normalized relative weight of the social factors equals 17%.

The global weight of the factors was calculated by multiplying the main clusters' normalized weight by the factor's normalized weight as shown in Table 4. The calculated global weights of the thirteen factors from F1 to F13 were as follows: 0.22, 0.15, 0.14, 0.14, 0.02, 0.05, 0.05, 0.05, 0.09, 0.04, 0.09, 0.07, and 0.11 respectively as shown in Table 4.

The proposed model is developed using the weighted scoring factors method [17]. The proposed model is generated mathematically using Eq. (1). Each factor is given a numerical value S_i (score) according to its degree of importance, one for the very low degree of importance, two for the low degree of

Table 4 Global weights of grade classification's factor.

Main Clusters	Factor	Global weight = normalized weight * main cluster weight
Economic	(F1) Project capital cost	(0.5 * 0.43) = 0.22
	(F2) Project operational and maintenance costs (O&M)	(0.5 * 0.29) = 0.15
	(F3) Payback period	(0.5 * 0.28) = 0.14
	(F4) Internal return ratio (IRR)	(0.5 * 0.28) = 0.14
Social	(F5) Effect on other nearest properties to the host pipes	(0.17 * 0.14) = 0.02
	(F6) Effect on traffic	(0.17 * 0.29) = 0.05
	(F7) Effect on public health	(0.17 * 0.29) = 0.05
	(F8) Effect on other nearest utilities to the host pipes	(0.17 * 0.29) = 0.05
Environmental	(F9) Effect on public safety	(0.33 * 0.13) = 0.09
	(F10) Effect on air quality	(0.33 * 0.07) = 0.04
	(F11) Effect on water quality	(0.33 * 0.27) = 0.09
	(F12) Noise effect	(0.33 * 0.20) = 0.07
	(F13) Energy saving	(0.33 * 0.33) = 0.11

importance, three for the medium degree of importance, four for the high degree of importance, and five for the very high degree of importance. The total score of the project equals the summation of the factors' adjustment value. The factor's adjustment value equals the multiplication of the factor's weight by the factor's score value (W_j * S_i). MS Excel can be used to generate the models mathematically.

$$\text{Project's total score} = \sum W_j^* S_i \tag{1}$$

where W_j: is the factor's relative weight, and S_i: is the factor's score from one to five. Projects with total score equals five will be classified as very high grade projects (V1), projects with total score equals four will be classified as high grade projects (V2), projects with total score equals three will be classified as medium grade projects (V3), projects with total score equals two will be classified as low grade projects (V4), and projects with total score equals one will be classified as very low grade projects (V5).

Projects ranking model

The project ranking model is developed to rank the projects at the same grade. The projects will be ranked in descending order according to their total scores. The budget will be given first to the project with high total score. Interviews with six experts and municipality engineers were conducted to gather a list of factors suitable for ranking the rehabilitation projects at the same grade [13]. Six factors were gathered which include the following: (C1) the internal water pressure in meter (m), (C2) the individual water consumption, (C3) project cost/served person, (C4) current age, (C5) pipes' break rate, and (C6) pipes' material type. A numerical grade scales system is established through interviews with the six (6) experts from their own practices and each value equals the average value of the expert's proposals as shown in Table 5. The proposed model is generated mathematically using Eq. (2). The model can be generated mathematically using the MS Excel.

$$\text{Total project score} = \sum F_j^* S_i \tag{2}$$

where F_j: The factor weight and S_i: The factor's grade scale.

Water mains budget allocation methodology

As shown in Fig. 2, the grade classification model classified the projects in descending order from V1 the very high grade to the V5 the very low grade. The available budget has only been distributed on Projects V1, V2, and V3. The remaining budget was insufficient to be distributed on the projects on part of grade V4 and grade V5. By using the project ranking model the projects on grade V4 have been ranked. The available budget will be sufficient to cover projects at grades, V1, V2, V3, and projects Rank1 and Rank2 on grade V4. Projects Rank4 and Rank5 on grade V4 and projects on grade V5 will be left to the next fiscal year.

Numerical example

It is assumed that the Holding company for potable water and wastewater has a total of 22 water mains rehabilitation projects in a fiscal year with a total budget 745 million Egyptian pounds. The actual budget that is available that year is not more than 600 million Egyptian pounds. In this situation, the Holding company is faced with the decision-making

Table 5 Factors grade scales (scores).

Factor	Weight F_j	Factor grade scales (scores) (S_i)					
		0	1	2	3	4	5
(C1) Internal water pressure (m)	0.20	⩾20	15–20	12–15	9–12	6–9	< 6
(C2) Individual water consumption	0.15	⩾Code	< Code (0–10%)	< Code (10–20%)	< Code (20–30%)	< Code (30–40%)	< Code (⩾40%)
(C3) Project's cost for served person	0.15	⩾500L.E/person	400–500	300–400	200–300	100–200	< 100
(C4) Current age of pipes	0.15	< 10 years	10–20	20–30	30–40	40–50	> 50
(C5) Pipes' break rate	0.27	No break	< 0.1b/k/y	0.1–0.5	0.5–1	1–2	> 2
(C6) Pipes' materials type	0.08	PVC	DI	Steel	Concrete	CI	AS

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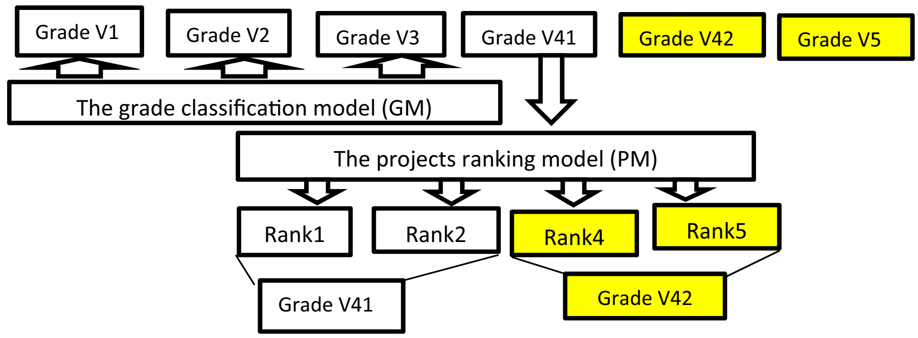

Figure 2 Sketch map for ranking projects and budget allocation of water mains rehabilitation projects.

Table 6 Total score calculation for project (P3).

Factor	Weight (W_j)	Score (S_i)	Total score ($W_j * S_i$)
(F1) Project capital cost	0.10	5	0.5
(F2) Project operational and maintenance costs	0.20	4	0.8
(F3) Payback period	0.10	3	0.3
(F4) Internal return ration (IRR)	0.10	2	0.2
(F5) Effect on other nearest properties to the host pipes	0.11	1	0.11
(F6) Effect on traffic	0.02	3	0.06
(F7) Effect on public health	0.02	2	0.04
(F8) Effect on other nearest utilities to the host pipes	0.02	4	0.08
(F9) Effect on public safety	0.09	5	0.45
(F10) Effect on air quality	0.11	3	0.33
(F11) Effect on water quality	0.04	2	0.08
(F12) Noise effect	0.07	1	0.07
(F13) Energy saving	0.02	4	0.08
Total score = $\sum W_j * S_i$			2

Table 7 Projects' total score.

Project ID	Project budget (million L.E)	Projects' total score
P1	10	1
P2	15	5
P3	17	2
P4	20	4
P5	22	3
P6	27	1
P7	32	3
P8	37	2
P9	40	3
P10	42	2
P11	47	3
P12	50	1
P13	55	5
P14	67	4
P15	75	3
P16	80	1
P17	12	1
P18	9	3
P19	7	4
P20	23	2
P21	28	1
P22	30	4

Table 8 Project's grade classification.

Projects	Grade	Total budget (million LE)
P1, P6, P12, P16, P17, P21	Grade (V5)	207
P3, P8, P10, P20	Grade (V4)	119
P5, P7, P9, P11, P15, P18	Grade (V3)	225
P4, P14, P19, P22	Grade (V2)	124
P2, P13	Grade (V1)	70
Total budget		745

problem of how to allocate the available budget and how to decide which projects ought to be executed. The grade classification model is applied by calculating the total project's score for each project. Table 6 illustrates the calculation of the total score for one project (P3). The experts gave a value (S_i) from one to five for each factor. The adjustment value for each factor is calculated by multiplying the factor's weight by its score value that has been selected from one to five according to the degree of importance of the particular factor. Score one will be selected if the degree of importance of the factor is very low, score two will be given if the degree of importance of the factor is low, score three will be given if the degree of importance of the factor is medium, score four will be given if the degree of importance of the factor is high, and score 5 will be given if the degree of importance of the factor is very high. The total sum of the last column in Table 6 gives the total project's score. The same calculations will be done for all projects. Table 7 illustrates the total scores for the 22 projects. Table 8 illustrates the grade classification of the 22 projects, whereas, the grade V5 includes the projects: P1, P6, P12, P16, P17, P21, grade V4 includes projects: P3, P8, P10 and P20, grade V3 includes projects: P5, P7, P9, P11, P15, and P18, grade V2 includes projects: P4, P14, P19, and P22, and grade V1 includes Projects: P2, and P13. The total budget of projects at V5 is 207 million L.E, the total budget of projects at grade V4 equals 119 million L.E, the total budget of projects at grade V3 equals 225 million L.E, the total budget of projects at grade V2 equals 124 million L.E, and the total budget of projects at grade V1 equals 70 million L.E. The 600 million available budget is sufficient for projects at grades, V1, V2, V3, and V4 in addition to Projects P1, and Project P6 at grade V5. The projects, P12, P16, P 17, and P21 at grade V5 will be left to the next fiscal year. Table 9 illustrates the project ranking at grade V5.

Table 9 Project's ranking at grade (V5).

Project ID	Project's total score	Project ranking	Project budget
P1	5	1	10
P6	4	2	27
P12	3	3	50
P16	3	3	80
P17	2	4	12
P21	1	5	28

Conclusions

This paper presented a budget allocation methodology for water mains rehabilitation projects. The proposed methodology aims to realize the optimal allocation of limited budgets. The proposed methodology uses the multi-criteria methods to allocate budget to the water mains rehabilitation projects. The proposed methodology integrates two models, the grade classification model, and the project ranking model. The proposed methodology integrates the Simos' procedure and the weighted scoring factors model to classify and evaluate the water mains rehabilitation projects. The project ranking model ranks the water mains rehabilitation projects at the same grade level according to a multi-criteria evaluation model. The available budget is allocated to projects from the highest grade to the lowest grade. The highest grade takes the budget first, and if still budget left, the remaining budget is allocated to projects that at the next level. If the remaining budget is insufficient to be allocated at the next level, the projects at this level should be ranked using the project ranking model.

Conflict of interest

No conflict.

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